Study on the suitable lighting design of Beato Angelico's artworks displayed at the National Museum of San Matteo in Pisa (Italy)

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Study on the suitable lighting design of Beato Angelico's artworks displayed at the National Museum of San Matteo in Pisa (Italy)

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Abstract. The lighting design of exhibition space has a great impact on visual and colour perception and different lighting arrangements can create very different visual impression of artworks and, if not carefully designed, compromise the enjoyment of the viewers. This study involved the design of a new lighting solution for two of Beato Angelico's artworks displayed at the National Museum of San Matteo (Pisa, Italy). Multiple test lighting configurations were designed using different LED luminaires and different settings of the luminaires. The test lighting configurations were evaluated by a restricted group of observers through a survey in order to individuate the most suitable solution, able to enhance the two artworks simultaneously and to provide a good visual experience for museum visitors.

1. Introduction

Museum exhibitions are strongly affected by the features of the space where they are realized, the design of the exhibition path and, especially, the lighting design [1,2]. Architectural and lighting parameters have a huge impact on the visual perception of art exhibitions for museum visitors, and, if carefully designed, they can achieve the best enhancement of the displayed artworks and a great visual experience for the observers [3,4]. The beauty and uniqueness of each piece of art could not be properly perceived and appreciated without a good lighting project of the museum exhibition space, able to create the proper colour appearance of the artworks, the visibility of all details and the proper atmosphere in the exhibition space [5-8]. The lighting arrangement creates a determined relationship between the exhibits, the background and the surround of the exhibition space, depending on the purpose of the exhibition and the feelings that it should inspire to the viewers. In particular, the setting of the luminaires and the selection of the suitable type of luminaire (as well as a combination of different light sources) represent a crucial step when designing art exhibitions, because different layouts can create different lighting effects, firstly on the artworks, secondly on the overall exhibition space [9-11]. However light is one of the main causes of damage for the artworks, since it can cause fading and desegregation of sensitive materials, therefore the current legislation provides limitations of illuminance levels and annual luminous exposure, according to the level of sensitivity of the artworks' materials [12,13]. In this context, LED light sources represent a technological solution which allows a remarkable flexibility on the colorimetric choices, aimed to the improvement of the artworks perception [14], together with high energy performance, evermore required also in the lighting of cultural heritage [15,16].
In this paper a suitable lighting configuration aimed to guarantee the simultaneous properly perception of two artworks, displayed at the National Museum of San Matteo in Pisa (Italy), was investigated and discussed. The study is characterized as a scientific investigation, preparatory for an effective lighting design stage, from which guide information on the observer preference can be obtained. The artworks were painted by Beato Angelico during the 14th century (right on Figure 1): one gold-ground panel painting, the *Madonna dell'umiltà* (1423), and one old banner painted on fabric, the *Redentore benedicente* (1440-1445), that was recently restored. These artworks were classified by the Curator of the Museum of San Matteo as "low sensitivity" materials [13]. The two artworks, extremely different

for style and dimensions, are displayed next to each other in a room, with other artworks, where the lighting system was not modified with respect to the previous mounting. The study tested multiple lighting configurations, obtained with different LED luminaires (with different optical systems) and different settings of the luminaires. The test lighting configurations were first measured and then evaluated by a group of observers, in order to point out the most suitable one for the enhancement of both artworks and a clear visibility of all their features and details.

2. Brief historical notes on the National Museum of San Matteo

The Museum of San Matteo in Pisa (Italy) is placed in the medieval monastery of San Matteo, which hosts the art collections since 1949. The exhibition halls are arranged on the first floor of the building, around the old courtyard of the monastery, the entrance of the museum overlooks the Arno River. The core of the art collection of the museum was owned by Sebastiano Zucchetti, who donated it to the Opera del Duomo of Pisa in 1796. Since the collection was enriched and extended through the years, it was moved to the former convent of San Francesco in 1893, which became the new Civic Museum of Pisa. During World War II, the Civic Museum was closed in order to protect the art collection form the potential bombing over the city, and next, between 1947 and 1949, the art collection was moved to the former monastery of San Matteo. The Museum consists of one of the most important collections of medieval painting and sculpture and it includes artworks of the most famous artists in Tuscany between the 11th century and the 13th century. This collection makes the Museum of San Matteo one of the main art galleries of medieval painting across Europe, especially for its collection of gold-ground panel paintings. During the years, the collection was enriched with more art pieces, such as the group of wooden sculptures, the sculptures from the Spina Church and the collection of ceramics.

Figure 1. Pictures of some exhibition rooms at the Museum of San Matteo: (top, left) Renaissance paintings room; (bottom, left) XIV-XV cen. paintings room; (right) the two Beato Angelico's artworks (panel painting *Madonna dell'umiltà* and old banner *Redentore benedicente* are easily recognizable).

3. Current lighting of the exhibition room

The current lighting of the exhibition rooms of the Museum of San Matteo is realized with halogen or LED spotlights set on tracks and fixed on the ceiling. Almost each artwork has its own direct lighting and there is a dim surround in most of the exhibition rooms, emphasised by the dark blue backgrounds

of many panel paintings (see also Figure 1). It is important to mention that the Museum of San Matteo is a historic building, thus there are many restrictions related to the electric system and the overall management of the exhibitions. At the same time, the exhibition path should be as more flexible as possible, in order to allow to be easily adapted and modified when new artworks are displayed or some of them are loaned to other museums. Currently, the *Madonna dell'umiltà* is illuminated by one spotlight set frontally, whilst the *Redentore benedicente* is illuminated only indirectly by the light sources directed into the other displayed artworks and its details and the figure of Christ are not clearly visible. Therefore, the current lighting overshadows the *Redentore benedicente* and draws all the attention to the *Madonna dell'umiltà*, which appears more highlighted. In this context a new lighting design, able to reduce the unbalanced lighting conditions, is hence required to enhance visual experience for museum visitors.

4. Experimental activity: design and procedure

Four different lighting configurations were designed for Beato Angelico's artworks and were evaluated through a survey by a small group of observers, in order to individuate the most suitable and pleasant solution. For this study, the group of observers consisted of five people with expertise in lighting design or art. The aim of the survey was obtaining a preference pattern that could be used as a guideline for the design of a future permanent lighting system. Recent researches on museum lighting [5-6,9-10,14] point out that lighting measurements and the fulfilment of quantitative standards (i.e. the annual amount of light or the traditional setting of the luminaires) are not sufficient to provide a good visual experience of art for the viewers and qualitative standards (i.e. comfort and preference) must be taken into account.

4.1 Experimental setup

The test lighting configurations were designed using a support frame 3.20 m high, positioned in front of the two artworks at a distance of 1.50 m. The two artworks are displayed side by side, almost 1.50 m distant from each other. The support frame, 3.20 m large, allowed to create different settings of the luminaires, positioned laterally or frontally in relation to the artworks. However, the structure was not large enough to allow a frontal lighting for both the artworks, which was realized for most of the artworks displayed in the museum. For this reason, two different setups were designed (Figure 2): the first setup allowed to frontally illuminate the *Redentore benedicente* and laterally the *Madonna dell'umiltà*, whilst the second setup allowed to frontally illuminate the *Madonna dell'umiltà* and laterally the *Redentore benedicente*.

4.2 Luminaires and lighting configurations

All test lighting configurations for Beato Angelico's artworks were designed using Zumtobel products [17], all of them specifically designed and tailored for museum lighting. Since the current lighting design of the exhibition room is made of halogen lamps with low CCT, it was decided to use luminaires with a CCT of 3000 K and 4000 K. Two types of luminaires were used: the ARCOS LED expert spotlights, with different dimensions (ARCOS 2 and ARCOS 3), a Correlated Colour Temperature (CCT) of 3000 K and nominal power of 30-35 W; the SUPERSYSTEM II spotlights, with different dimensions (Mini, Midi and Maxi), different CCTs (3000-4000 K) and nominal power of 5-10 W. All the spotlights had a Colour Rendering Index higher than 90. The luminaires were fixed on tracks on the support structures and they were positioned and tilted in order to illuminate the two artworks. Four lighting configurations were designed, two for each setup (Table 1): the first two configurations (A and B Configurations) involved a frontal lighting for the *Redentore benedicente* and a lateral lighting for the *Madonna dell'umiltà*, whilst the other two configurations (C and D Configurations) involved a frontal lighting for the *Madonna dell'umiltà* and a lateral lighting for the *Redentore benedicente*. The description and the schemes of the four test lighting configurations are illustrated in Table 1.

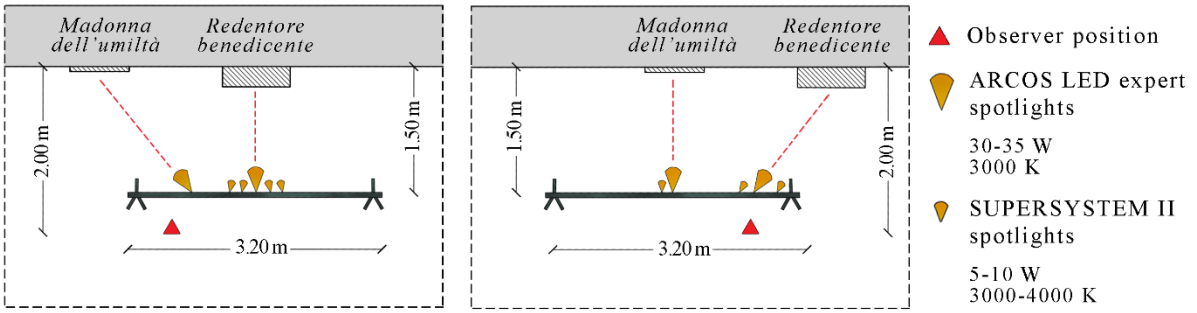
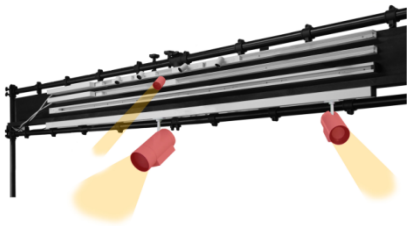
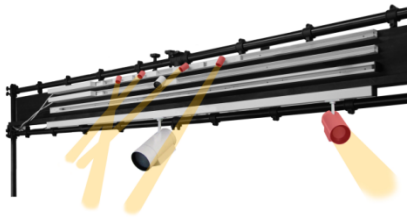
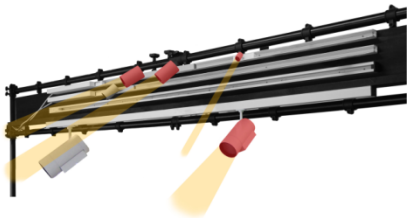
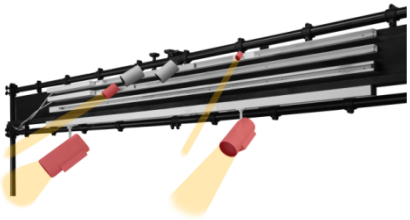


Figure 2. Plans of the luminaire setups designed for the test: (on the left) frontal lighting for the *Redentore benedicente*; (on the right) frontal lighting for the *Madonna dell'umiltà* (see also Table 1).

Table 1. Description and schemes of the four test lighting configurations.

Configuration A 	▪ The (lateral) lighting for the *Madonna dell'umiltà* was realized using an ARCOS 2 LED expert with a Flood optic and an opaque lens, able to illuminate the whole painting. ▪ The (frontal) lighting of the *Redentore benedicente* was realized with an ARCOS 3 LED expert with a Spot optic and a diffuse lens and a SUPERSYSTEM II (Midi) with a Spot optic, directed into the face of the Christ. ▪ All the luminaires had a CCT of 3000 K.
Configuration B 	▪ The (lateral) lighting for the *Madonna dell'umiltà* was realized using an ARCOS 2 LED expert (3000 K) with a Flood optic and an opaque lens. ▪ The (frontal) lighting of the *Redentore benedicente* was realized with four SUPERSYSTEM II (Mini), two of them with a CCT of 3000 K and a Spot optic and the other two with a CCT of 4000 K and a Superspot optic. ▪ The warm and cool light were mixed and directed on the artwork to uniformly illuminate it: a 3000 K spotlight and a 4000 K were directed into the upper area of the artworks, whilst the other two 3000 K and 4000 K spotlights were directed into the lower area of the artwork.
Configuration C 	▪ The (frontal) lighting for the *Madonna dell'umiltà* was realized using an ARCOS 2 LED expert with a Flood optic and an opaque lens, plus a SUPERSYSTEM II (Mini) with a Spot optic directed into the upper golden decorations of the artwork, representing Christ. ▪ The (lateral) lighting of the *Redentore benedicente* was realized with two SUPERSYSTEM II (Maxi), both with a Spot optic. ▪ All the luminaires had a CCT of 3000 K.
Configuration D 	▪ The (frontal) lighting for the *Madonna dell'umiltà* was realized using an ARCOS 2 LED expert with a Flood optic and an opaque lens, plus a SUPERSYSTEM II (Mini) with a Spot optic directed into the upper golden decorations of the artwork, representing Christ. ▪ The (lateral) lighting of the *Redentore benedicente* was realized with a lateral ARCOS 3 LED expert with a Spot optic and a diffuse lens and a SUPERSYSTEM II (Midi) directed into the face of the Christ. ▪ All the luminaires had a CCT of 3000 K.

4.3 Experimental procedure

The experimental procedure for each configuration started with manually dimming the luminaires in order to uniform the new lighting solution to the current lighting of the whole exhibition room. Since it was not possible to turn off the single luminaires of the exhibition room, the test was conducted in a dark environment and there were no interferences with the lighting of the other exhibition rooms. Some monitoring measurements were done in significant selected points of the artworks (the most representative areas of the two artworks), indicated in Figure 3. The measurements were conducted with portable instruments made available by Lighting and Acoustics Laboratory of the University of Pisa: a luxmeter PRC Krochmann model Radiolux 111 and a luminance meter Hagner model L-202. These instruments have accuracy classes of "A" and "B" respectively, according to the Italian Technical Standard UNI 11142/2004. Moreover, the exposure of the artworks to UV light emitted by the lighting system was also assessed using a photoradiometer Delta Ohm model HD2102.1, equipped with a suitable irradiance probe. The measured illuminance and luminance values are summarized in Table 2, whilst the UV content was found to be negligible for all the lighting configurations.
The four lighting configurations were evaluated separately by a restricted group of five observers, with an average age 36 years. After turning on a configuration, it was first measured (measuring the illuminance, the luminance and the UV content on the surfaces of the two artworks) and then evaluated. The observers evaluated two parameters on a 6 points scale (without neutral response): the 'enhancement of the artworks' and their 'personal preference'. The observer position during the test was fixed between the two artworks, at a distance of 2.0 m from the wall. This position allowed to have a good visibility of both artworks at the same time and prevented any reflections or glare effect on the surfaces of the artworks that could have compromise the evaluations.

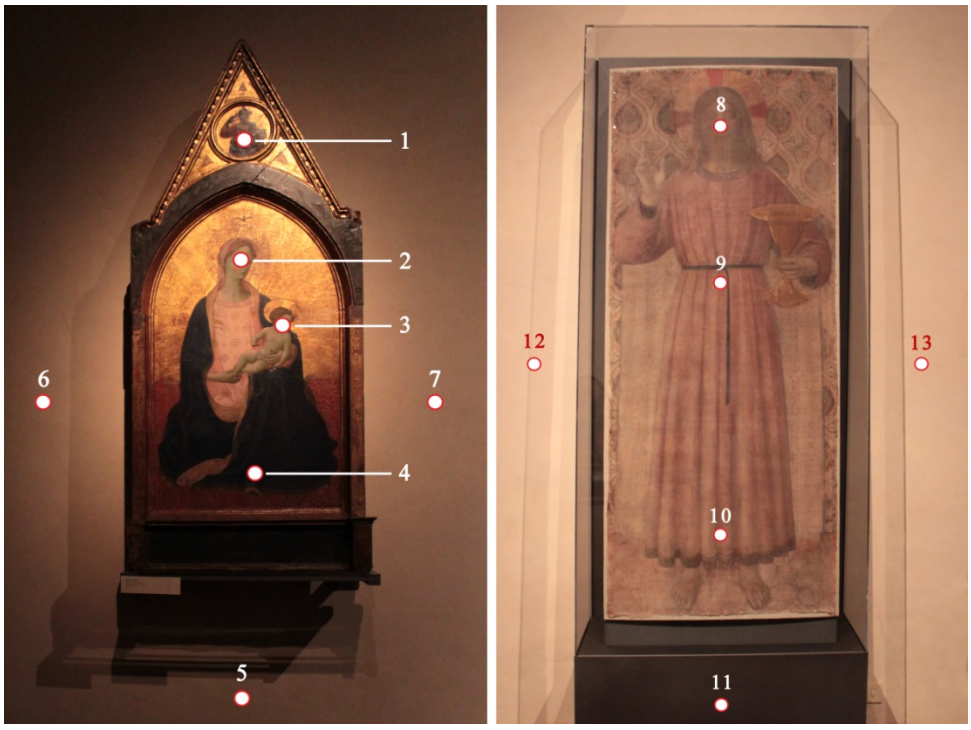


Figure 3. Measurement points selected on the *Madonna dell'umiltà* and the *Redentore benedicente*.

5. Results and discussion

The results were analysed by computing the means of the evaluations for each parameters, shown in Figure 4. From the graphs, it is clear that C and D Configurations were evaluated, on average, as more

suitable for the enhancement of the artworks and more pleasant for the observers than A and B Configurations. C and D Configurations were appeared to be equally suitable for enhancing the artworks, whilst C Configuration was appeared to be the most appreciated lighting configuration (see also Figure 5). On the other hand, B Configuration was the least appreciated, probably because of the use of cooler light (4000 K).

Table 2. Illuminance and luminance measured values on the two artworks.

		Current Lighting		Test lighting configurations							
				A		**B**		**C**		**D**	
Artwork	Meas. Point	E (lx)	L (cd/m^2)	E (lx)	L (cd/m^2)	E (lx)	L (cd/m^2)	E (lx)	L (cd/m^2)	E (lx)	L (cd/m^2)
Madonna dell'umiltà	**1**	65	4.2	181	2.4	183	3.3	202	5.6	494	10.5
	2	140	9.0	296	14	272	14	213	14.3	355	31.5
	3	118	7.2	297	15.4	316	15.7	214	32.3	260	64.5
	4	35	1.3	187	5.1	186	4.9	168	4.6	171	4.8
	5	16	3.4	38	6.4	39	4.4	46	8.0	46	8.5
	6	25	4.1	121	18.5	137	16.5	72	11.2	89	15.3
	7	40	7.2	84	22.1	78	20.4	102	16.7	98	19.2
Redentore benedicente	**8**	80	4.1	396	12.7	923	26	814	24.4	725	23
	9	78	3.6	318	11.7	567	20	620	20.1	219	22.3
	10	67	2.8	122	3.2	151	4.2	312	7.1	229	6.0
	11	45	1.0	36	0.6	24	0.5	70	1.0	90	1.4
	12	55	8.4	58	10	33	9.8	62	9.8	95	13.5
	13	42	11	89	19.2	37	6.0	175	25.2	273	39.9

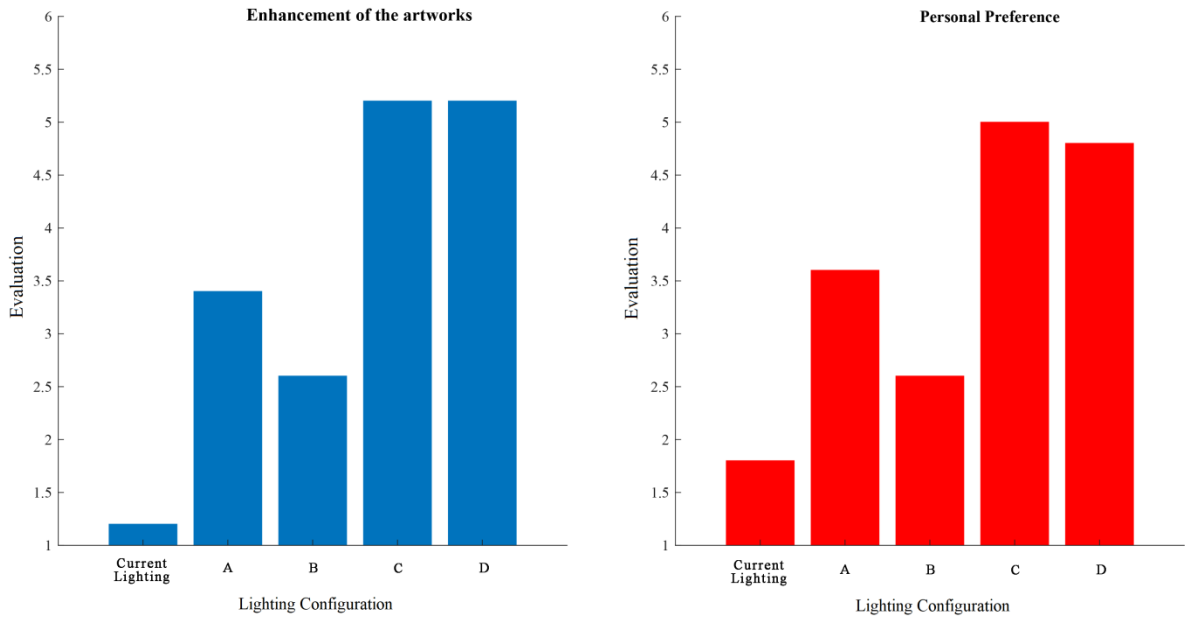


Figure 4. Results of the evaluation of the 'enhancement of the artworks' (on the left) and of the 'personal preference' (on the right) for the different test lighting configurations.

As regard the lighting measurements, it can be noticed from Table 2 that the illuminance levels on the artworks, for all the lighting configurations, were higher than those measured for the current lighting. In some cases the increases in the illuminance level were very significant (e.g. the average illuminance on the *Redentore benedicente* was increased from 75 lx of the current lighting to 582 lx of the C Configuration), but the higher illuminance level provided a better visual perception of the artworks ad a clear visibility of all their details. Although the illuminance levels are significantly increased, the annual luminous exposure limitation, fixed for this type of artworks [12], could be respected using control systems to limit the exposure time to the light, according to the annual opening hours. Since the lighting of each exhibition room is independent from the others, movement sensors could be installed in the exhibition room or in front of Beato Angelico's artworks, so that the lighting turns on only when visitors walk into the room. Among the test configurations, those preferred by the observers were characterized by the higher values of the luminance ratio between artworks and background, without overcoming the maximum limit value of 3. Usually, the range 1/3-3 can guarantee the adequate eye's adaptation [18]. It is possible to notice that A, C and D Configurations provided similar luminance ratios on the *Madonna del Latte* and the *Redentore Benedicente*, whilst B Configuration (the least appreciated) provided the higher luminance ratio on the *Redentore Benedicente* and a very low luminance ratio on the *Madonna del Latte,* creating a non-uniform lighting effect between the two artworks.

Figure 5. Test lighting configuration preferred (C Configuration).

6. Conclusions and future developments

This study analysed a preliminary lighting arrangement for two of Beato Angelico's artworks displayed at the National Museum of San Matteo. Multiple test lighting configurations were designed for the two artworks using Zumtobel LED luminaires with different characteristics. The four test lighting configurations were evaluated through a survey by five observers with expertise in lighting design or art. The observers had to assess the enhancement of the artworks and their personal preference for all test lighting configurations. The test results show that the C and D Configurations were the most appreciated by the observers, whilst B Configuration was the least appreciated and evaluated as the least suitable for the enhancement of the two artworks. Furthermore, C and D Configurations created more uniform solutions between the two artworks, providing similar luminance ratios between the artworks and their background.

The study described in this paper is part of a wider research activities about visual perception of artworks displayed in museum settings. The project was carried out at the Museum of San Matteo and consisted of the measurements of various lighting configurations designed for two artworks, the panel painting *Sacra Conversazione* by Ghirlandaio (1479) and the sculpture *Madonna del Latte* by Nino and Andrea Pisano (1343-1347), and the investigation of preference patterns for a group of observers, both expert and naïve. The study on Beato Angelico's artworks could be further developed by extending the number of observers of the experiment and involving naïve observers, whose evaluations would be compared to the ones made by expert observers presented in this paper.

Acknowledgments

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